Electrical Tech Note — 322

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Phase Converters

A phase converter is a device that permits a 3-phase electrical load to be operated from a single-phase supply. Most frequently, the 3-phase device supplied is an electric motor. In some locations the serving utility may not be able to cost effectively provide 3-phase power to a customer. In these cases, the customer must find an alternative method of providing 3-phase power to meet te requirement of the load. Sometimes 3-phase power is available to the customer, but the need for 3-phase power at the customer's facility may be only limited and not practical to rewire the facility. For whatever reason, there are cases where there needs to be a means of occasionally being able to operate a 3-phase load from a single-phase supply. A phase converter makes such operation possible. It is important to understand the different types of phase converters and the principles of operation of the entire phase converter circuit. Rules for installing phase converter circuits are found in *Article 455* of the *National Electrical Code®* (*NEC®*)[1].

Single-Phase and 3-Phase Current: A diagram of a 3-phase load supplied from a single-phase supply is shown in Figure 322.1. Note there are only two wires supplying the phase converter, and there are three wires between the phase converter and the load. If there are only two single-phase wires, the current flowing on them will be higher than on the three wires to the load. If there are no losses at the phase converter, the ratio of single-phase current to 3-phase current will be 1.73 to 1. There will be losses in the phase converter that result in more single-phase current flow into the phase converter than is required to supply the load. These losses vary depending upon the design and type of phase converter. The *NEC* uses a ratio of 2.5 to 1 for single-phase current to 3-phase current.

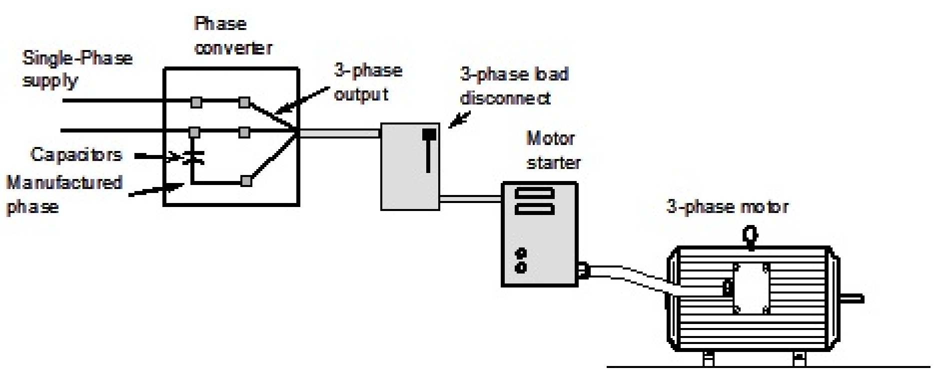


Figure 322.1 Two wires supply the phase converter and 3 wires supply the load from the phase converter. The theoretical current ratio of single-phase current to 3-phase

[1]*National Electrical Code* and *NEC* are registered trade marks of the National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471. Copies can be obtained at most electrical wholesale distributors, on-line book sellers, and at NFPA.

current is 1.73 to 1, but considering system losses the ratio is more like 2.5 to 1.

One of the 3-phase wires between the phase converter and the load is called the *manufactured phase*. Two of the wires to the 3-phase load are solidly connected to the input single-phase wires as shown in Figure 322.1. The manufactured phase is connected to the input single-phase wires through a capacitor or through a capacitor and an inductor. This manufactured phase is required by the *NEC* to be identified by a distinctive marking. The *NEC* prohibits single-phase loads from being connected to the manufactured phase. A typical single-phase load would be a motor control circuit for a motor starter as illustrated in Figure 322.2. Make sure when connecting the control circuit (generally single-phase circuits) that it is connected between the two phase wires that have a direct connection to the input single-phase wires. If this procedure is not followed, it is possible for control system component failure to occur. The voltage between the manufactured phase and either of the other phase conductors may not remain constant through the operation of the equipment, and control system malfunction or failure may occur.

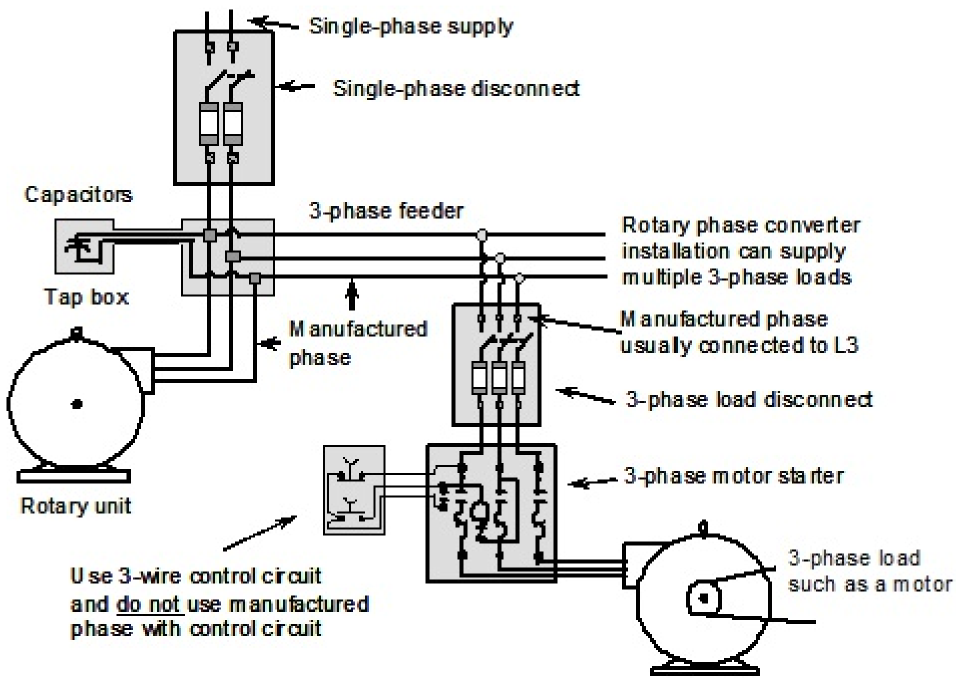


Figure 322.2 A rotary phase converter usually consists of a separate rotary unit and capacitor panel. The manufactured phase originates at the phase converter and is not permitted to supply any single-phase loads such as motor control circuits.

How a Phase Converter Works: The current flowing in the three wires of a 3-phase electrical system are out-of-phase of each other by 120° (shifted by 5.56 ms). There are three windings in a basic 2-pole 3-phase motor, and when current is supplied to each winding, a magnetic field is produced in the motor that rotates at synchronous speed. When the same motor is supplied with single-phase power, the current in one wire is in-phase with the current in the other wire. This current flows through two of the 3-phase motor's windings and a non-rotating magnetic field is produced. This is illustrated for a 3-phase motor with wye connected windings in Figure 322.3. By connecting a capacitor between one of the input wires and the unused lead of the motor, a current will flow through the third winding that is out-of-phase with the current in the other two windings. This connection is also illustrated in Figure 322.3. If the correct capacitance is chosen for the motor and load, the current through the motor windings will be similar to the case where the motor is energized with true 3-phase power.

Generally a higher level of capacitance is needed for starting the motor than for running. It is common to have a starting circuit that inserts extra capacitors that are taken out of the circuit once the motor reaches full rpm. Supplying a 3-phase motor from a single-phase supply does generally result in some reduction of starting torque as compared to operating the motor from a 3-phase electrical supply. Powering a hard starting load such as a compressor with a 3-phase motor and phase converter is not recommended unless approved by the phase converter manufacturer.

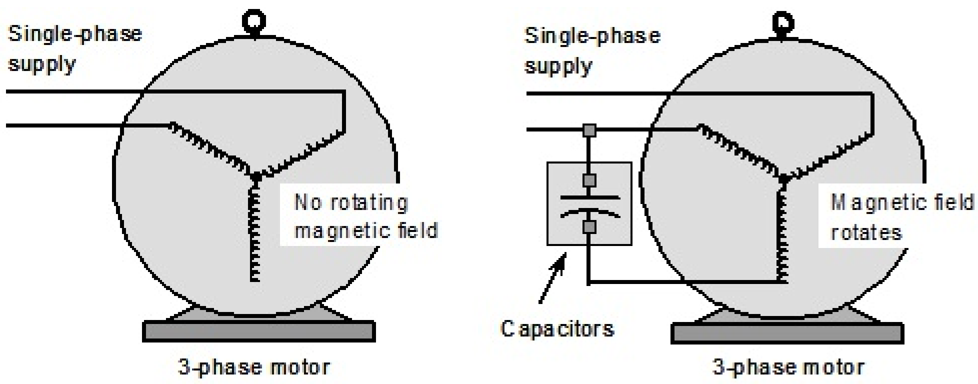


Figure 322.3 A 3-phase motor will not start if energized from a single-phase source, but a third phase can be produced by connecting the unused winding lead of the motor to one of the single-phase lines through a bank of capacitors.

Types of Phase Converters: Phase converters are of two types, static and rotary. Both allow operation of a 3-phase load from a single-phase supply. Cost, circuit simplicity, and flexibility at adapting the system to different applications are key factors when choosing a system.

A *static* phase converter does not have any moving parts except perhaps in some cases a solenoid that may be used to connect extra capacitors during starting. A simple static phase converter is similar to the one shown in the diagram of Figure 322.1. Some static phase converters will have an autotransformer, as shown in Figure 322.4, to help stabilize the voltages supplied to the motor. As the load on the motor changes, the voltages between the different phase combinations may not be stable, and the autotransformer helps to correct this problem.

Figure 322.4 Some static phase converters use an autotransformer to help insure stable voltages to the 3-phase motor leads.

Static phase converters are sized to match one specific motor. A 5 horsepower static phase converter can only provide power for a 5 horsepower 3-phase motor. There is a difference in the performance of phase converters from different manufacturers. Generally the full horsepower rating of the 3-phase motor cannot be expected when operated from a static phase converter. It is not uncommon to only get 60% to 80% of 3-phase motor horsepower when operated with a static phase converter. The performance of some static phase converters may be higher. This means a 3-phase motor may need to be oversized for the load because it's horsepower must be derated when operated using a static phase converter. Check the phase converter manufacturer recommendations to determine if horsepower derating is necessary, and if so, the level of derating that must be applied.

A *rotary phase* converter uses a 3-phase motor as a rotating transformer to produce the third phase. No load is extracted from the rotary unit, sometimes referred to as the idler motor. The rotary unit has two leads energized from the single-phase supply, and power is supplied to the third lead through a bank of capacitors. An advantage of this type of phase converter is that it is not required to be matched exactly to the load. There will be a maximum single load rating and a minimum load rating for the rotary phase converter. As long as any one load is sized between these two values, the phase converter can be used to power the load. Another advantage of the rotary phase converter is that it can supply several 3-phase loads simultaneously. It is generally necessary to start the loads individually. This can be done manually, or automatically using time delay relays. A rotary phase converter circuit supplying several motors is illustrated in Figure 322.5.

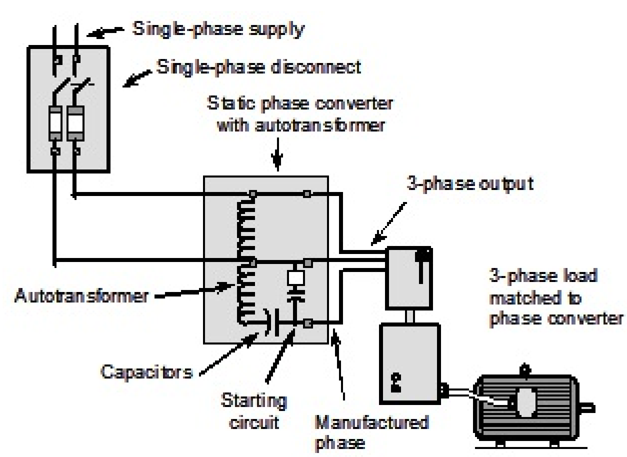
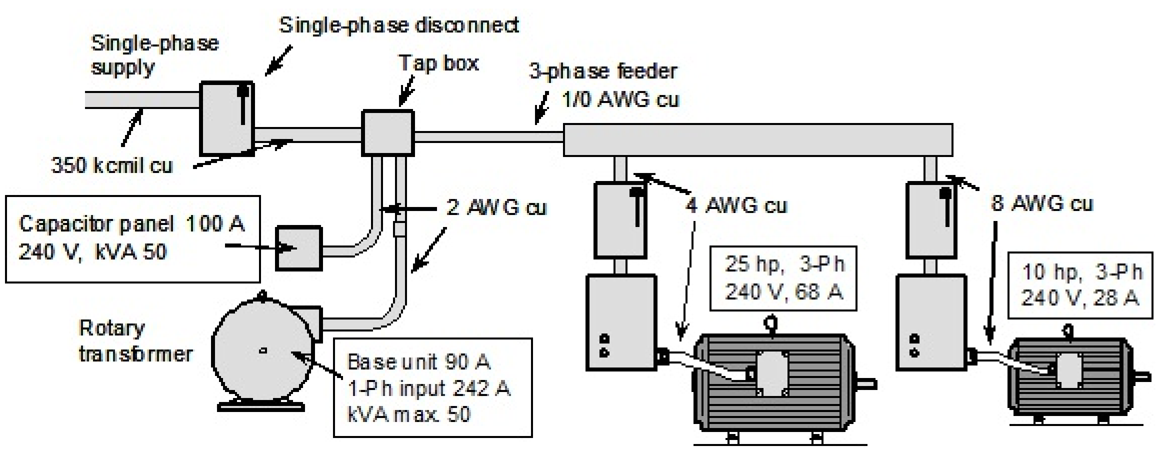


Figure 322.5 A rotary phase converter consists of a rotary unit and a bank of capacitors that convert single-phase power to 3-phase power. A rotary phase converter is capable of supplying several 3-phase loads simultaneously.

There is a caution with a rotary phase converter. The rotary unit must be started and up to full rpm before any loads can be applied. This would mean the rotary phase converter must be protected from momentary power interruptions that would shut down the system. One way to protect the phase converter in case of a momentary power interruption is to operate all 3-phase loads through a magnetic starter with a 3-wire control circuit. A 3-wire control circuit will automatically stop and require restarting if there is a power loss. Another method is to provide a time-delay restarting circuit.



Ratings of Phase Converters: A static phase converter must be sized for a specific motor. The nameplate on the phase converter will give the input single-phase full-load current. As directed in the *NEC* the minimum size input single-phase conductors are to have an ampere rating not less than 1.25 times the input full-load current marked on the nameplate.

A rotary phase converter is capable of supplying several loads simultaneously. The nameplate is required to state the largest single load the phase converter is capable of supplying. Additional loads are permitted to be added but not to exceed the maximum kVA rating of the phase converter as stated on the nameplate. A general rule is to assume one horsepower is equal to one kVA. A problem unique to the rotary phase converter is that the rotating unit must be carrying sufficient current to build a strong enough magnetic field for proper operation. The nameplate of a rotary phase converter unit will state the minimum kVA load that is required for proper operation. A phase converter nameplate meeting the requirements of *NEC* is shown in Figure 322.6 along with a nameplate for a separate phase converter capacitor bank. Sometimes the capacitors and the rotary unit are supplied as one complete unit. For the larger units, the rotary unit and the capacitors are supplied separately and connected at a tap box as shown in Figure 322.4.

Figure 322.6 The nameplate of the rotary unit of a phase converter is required to supply the maximum total kVA 3-phase load that can be supplied, the single maximum kVA load that the unit is capable of starting and the minimum kVA total load required for proper operation. In addition the maximum output 3-phase current and the maximum input single-phase current is required to be provided. The nameplate on the right is for the separate capacitor bank required for the rotary unit.